ART. VI. — *Lectures on Heat considered as a Mode of Motion: being a Course of Twelve Lectures delivered at the Royal Institution of Great Britain in the Season of* 1862. By JOHN TYNDALL, F. R. S., &c., Professor of Natural Philosophy in the Royal Institution. With Illustrations. New York: D. Appleton & Co. 1863. 12mo. pp. 480.

A FEW years ago the scientific men of Europe were delighted as well as astonished by the wonderful discovery of Kirchoff and Bunsen, that the light from many metals in combustion, when decomposed by the prism, gives a spectrum marked with transverse lines, — a fact already observed by Fraunhofer in the sun's spectrum, — and that these lines vary in size and position as the substance is changed. The lines formed by a large series of substances were noted, and, on comparing them with those produced by the sun, it was discovered that, among many other elements, iron plays a principal part in the luminous atmosphere around that body. There seemed no obstacle to a full and intimate knowledge of the fuel of that great fire, which at the distance of ninety-five millions of miles furnishes us with light and heat.

Fortunately, before a full chemical analysis of the sun's particles had been published, it was discovered that the degree of heat to which the substance was subjected was an important factor in the spectrum produced. Until, then, we ascertain the temperature of the sun's surface, and can distinguish the luminous photosphere from the solid cone which it surrounds, this process will not reveal us the exact constitution of the great luminary. For a moment the weakness of human knowledge is shown. But, far from being discouraged, science is pushing its way on in another direction, which may at last establish the results of Kirchoff and Bunsen. We turn from the sun's light, and regard its other munificent gift, heat; and it is our purpose to glance at the results of the latest theory of heat, following for our guide an author well known to science, especially by his work on the Glaciers of the Alps.

The old theories of heat are well known; but at present the theory that heat is a substance united in certain definite pro-

portions to ponderable matter seems to be losing ground; while to take its place we are offered the theory that heat is a result of molecular action, — as we know it is a result of friction. This theory of molecular motion is the one amplified and illustrated in the Lectures which have been made the basis of this article; and whatever importance be attached to the Lectures themselves, it cannot fail to be observed that the present theory more simply, more clearly, and more satisfactorily than any other explains the phenomena of heat with which we are all familiar. Indeed, the importance of investigating the causes and relations of heat — that potent force which seems indeed the lever by which the Almighty moves the earth and conducts all the operations of nature, from the dew which falls noiselessly while we sleep, to the volcano bursting from its prison, hurling itself high into the air to bury cities and countries — far transcends the ordinary labors and themes of the laboratory and scientific societies.

As in the vast arrangements of the universe, so in the microcosm of man, heat is all-important. When heat is no longer produced, we die; when more than is needed is produced, we are feverish; and if it be increased still more, we are consumed. By the heat of our body we are able to raise our arms to work, and by the motion heat is consumed and passes off into the air.

With the importance of the results at which we may arrive constantly in view, the energies of men have been strained to catch the first glimpse of order, to obtain the clew which shall lead them through the labyrinth of nature's laws. Heat has long seemed the focus to which all the searchers for the correlation of forces have been tending. Foremost in years past was Rumford, who, by his famous experiment of boiling water by the heat evolved in boring a cylinder of iron by a rod of steel, demonstrated the conversion of mechanical force into heat; and he further proved that heat in the iron was inexhaustible. As long as iron remained to be rubbed, so long was heat evolved; thus proving that there could be no definite combination of heat with the iron.

Joule in England and Mayer in Germany pursued their investigations still further, and measured the mechanical force,

finding that, to raise one pound of water one degree Fahrenheit in temperature, as much heat was required as would, if applied mechanically, raise seven hundred and seventy-two pounds one foot. This gives us the *mechanical equivalent* of heat. From the English investigator this is often called Joule's equivalent.

The sun in former ages gave light and heat to trees and plants which have since been converted into coal, to be again used as the storehouses from which we draw light and warmth. To form the coal, heat was taken; in destroying it, heat is evolved; and every degree of heat imparted to a fern in the coal-ages of the world can be ascertained by the amount of work it will do. The same degree of mechanical force, however applied, will always produce the same degree of heat. Instead of using the coal reservoirs of concentrated heat, we can use the less convenient but equally potent sun-heat of to-day. Indeed, in the seventeenth century the sun was used to raise water from mines and to supply fountains, — the very purpose for which the steam-engine was invented. The sun's heat of to-day gives life to the plants, and by eating these plants animals produce heat, which in its turn produces work. In whatever way either heat or motion is produced, an exact equivalent of the other is consumed.

The theory of equivalents has not, indeed, been carried to its fullest extent. The equivalents into which heat may be resolved are not all determined, and those that are well known are so adapted to a course of experimental lectures, that, when deprived of the illustration by experiment which an apparatus so expensive as that of the Royal Institution permits, their mere statement seems bare of results. Description cannot supply the sight of actual observation; yet, to convey a just idea of the "mechanical theory," we may rely partly on experiments well known, while several of the more novel experiments are worthy the attempt at a brief description.

What the telescope is to the astronomer, the *thermo-electric pile* is to the student of heat. This little instrument, which wholly displaces the common thermometer in delicate experiments, is simply a series of bars of bismuth and antimony arranged alternately, and soldered at their ends. This combination possesses the remarkable property of exciting an electric

current when the temperature of the opposite ends or points of juncture of the bars varies. Such is the delicacy of this instrument, that the warmth of the hand, placed several feet from the end of the multiplier, will excite a strong current. The force of the current can of course be measured by any galvanometer. With this delicate index we arrive at the most pleasing results. Variations in temperature which have been the parents of elaborate theories, could never have been detected by any other known means.

Examples to illustrate this theory of heat may be taken from the work of man; but the illustrations Nature offers should claim our first attention. The theory being that heat is a motion, let us first see where it is produced by motion. By a sensitive thermometer, we find that the water of the Niagara River is warmed several degrees by its violent motion over the falls. Water, as is well known, is difficult to heat, and so great motion might well be required to heat the vast body in this case even three degrees. The sailor's tradition, that the ocean is warmer after a storm, is perfectly true; for the motion of a wave against its neighbor-wave produces a degree of heat which even the winds that cause the motion share, without being able to render it insensible. The effect is grander in the heavens, where the motion is greater. The most probable theory of the shooting stars supposes them to be small planetary bodies drawn from their orbits by the attraction of the earth, and heated to incandescence, or even dissipated in vapor by friction against our atmosphere, which thus proves to be an armor sufficient to protect us from celestial bombardment.

When motion is suddenly converted into heat, the elevation of temperature is far greater than would be supposed. Thus, a leaden rifle-ball, moving at a velocity of two hundred and twenty-three feet a second, on striking a target would raise the temperature of itself and the target together thirty degrees. The iron shot used in recent experiments on iron-clad ships have their motion converted into such a degree of heat as to cause flashes of light whenever they strike. From such data, we can calculate the effect of a sudden stoppage of the earth in her orbit. The calculation has been made by Mayer

and Helmholtz, and it is found that the heat generated by this colossal shock would not only fuse the entire earth, but reduce it in great part to vapor. Thus might "the elements" be caused "to melt with fervent heat." Hence has arisen a speculation on the mode in which the supply of light and heat is kept up in the sun, and it is held by some philosophers that the zodiacal light is a cloud of meteoric bodies, and that they are constantly showering down upon the sun, thus converting their motion into heat. A body of the size of the earth falling into the sun would supply it with heat for a century. Professor Tyndall remarks, that the force, if in sufficient operation, is fully competent to produce the effects ascribed to it.

Let us follow Tyndall, or rather Mayer of Heilbronn, whom he quotes, still farther on this path. If we suppose an asteroid approaching the sun from an infinite distance, its velocity just before striking the sun would be three hundred and ninety miles a second. On striking the sun, the asteroid would develop more heat than could be generated by the combustion of nine thousand equal asteroids of coal. Little does it matter, then, whether these bodies be combustible or not; for even the most combustible material could add but little to the tremendous heat produced by the mechanical collision.

If this is the true source of the sun's heat, as we have seen it to be the competent source, the sun must constantly increase in bulk. Very true; but the quantity of matter necessary to produce the observed calorific emission, even accumulated for four thousand years, could not be detected by our most delicate instruments. The tides that rub against the wharves of Boston produce little apparent heat; but this is because a great part is dissipated into space. It is an interesting question what supplies this waste. The tidal wave always lies to the east of the moon's meridian, and by the satellite's attraction the wave is as it were dragged like a brake over the surface of the revolving earth. The friction thus generated supplies the heat constantly evaporated into space, so that the heat produced by the friction of millstones moved by the tidal action has a very different source from the heat produced by a similar mechanical contrivance moved by a mountain stream. The former is produced by the earth's rotation, the latter by the sun's radiation.

Thus we have seen examples of motion converted into heat. Besides the steam and caloric engines, we have other and simpler illustrations of the conversion of heat into motion.

In 1805, in one of the smelting works of Saxony, a mass of silver which had been fused in a ladle was allowed to solidify, and then was placed on an anvil to hasten its cooling. Soon a strange, buzzing sound was heard, which was finally traced to the hot silver which was found quivering on the anvil. More than twenty years after this, Trevelyan made a similar incident the subject of a careful series of experiments. The substances and the forms best suited to produce the effect were ascertained. The vibrating substance is called the "rocker," and the experiment can be performed by balancing a heated brass poker on two edges of sheet-lead half an inch asunder, when a musical tone will be produced. The principle is this: the hot surface in contact with the lead raises a nipple on the surface of the lead by expansion, which tilts up the rocker, throwing the heat into another place, where the operation is repeated; the vibrations being rapid enough to produce a note. The same effect is often noticed when a tea-kettle is placed on a hot stove.

A grander though not more wonderful example of motion produced by heat is seen in the Great Geyser of Iceland. This consists of a tube seventy-four feet deep and ten in diameter, surmounted by a basin fifty-two feet across from north to south, and sixty feet from east to west. The interior of the tube and basin is covered with a beautiful siliceous plaster, so hard as to resist the blows of a hammer. "Previous to an irruption, both the tube and basin are filled with hot water; detonations which shake the ground are heard at intervals, and each is succeeded by a violent agitation of the water in the basin. The water in the pipe is lifted up so as to form an eminence in the basin, and an overflow is the consequence." Professor Bunsen succeeded in determining the exact temperature of the tube from top to bottom a few minutes before a great irruption; and these observations revealed the astonishing fact, that in no part of the tube did the water reach its boiling point. Knowing the temperature of the tube, Professor Bunsen explains the action in this simple way. At a point, A, thirty feet

from the bottom, the boiling point of the water is 123.8° C., while its observed temperature is 121.8° C. At a point six feet above, or thirty-six from the bottom, which we will call B, the boiling point is only 120.8°. When, therefore, these detonations occur (caused by local generation of steam), which elevate the water in the tube at least six feet, the water at A, heated to 121.8°, is carried to B, where its boiling point is only 120.8°. The excess of heat instantly generates steam; the column is elevated higher, and the water below is further relieved. More steam is generated; the column of water bursts into ebullition from the middle downward; the water above, mixed with steam, is ejected into the air. This beautiful theory can be verified by experimenting with an iron tube six feet long instead of seventy-four.

Pressure increased the boiling point in the long column of water, and the same thing occurs in another form where the melting point of solids is raised by pressure. All solid substances which expand on assuming the liquid form may be exposed to a much higher temperature, if the pressure is increased, without melting. Hence it has been supposed that the crust of our earth may be much thicker than has been stated, since the enormous pressure to which the interior of the earth is subjected would require a very high temperature in order for it to assume the liquid state, — much higher, in fact, than the calculated heat of the interior of the solid crust, as now figured in geological or physiographical charts.

One more example of the forces into which heat resolves itself, and that is one familiar to many. We refer to the expansion of water by freezing. In the third Lecture of the present series, Professor Tyndall exhibited two iron bottles, — the walls more than half an inch thick, — which he completely filled with water, closing the apertures with a screw. These were placed in a freezing mixture, and the water, expanding as it turned to ice, required more room, and pressed against the rigid iron walls of its prison. "The rigidity of the iron is powerless in the presence of the atomic forces. These atoms are giants in disguise; you hear that sound; the bottle is shivered by the crystallizing molecules, — there goes the other; and here are the fragments of the vessels, which show their

thickness and impress you with the might of that energy by which they were thus riven." This wonderful property of water, which causes it to expand and thus to grow lighter when frozen, alone keeps our ponds and rivers from becoming in a single winter a solid mass, which our summer's heat would be wholly incompetent to melt.

We have seen instances of the heat produced by motion, and also of the conversion of heat into motion; we may now examine briefly the motion of heat itself. We find it reflected, conducted, and absorbed; but it is only its absorption that we can notice now. Experiments have been tried by passing the rays of heat through a vacuum, and through air and different gases, and it is found that, while sulphurous acid absorbs 8,800 rays of heat, *dry* air absorbs only one. On a dry day, therefore, the sun's rays come to us with their greatest intensity; and likewise, in a dry, clear night the heat passes away from the earth with the greatest rapidity into space, almost without hinderance. Moisture in the air absorbs the rays of heat to a great extent, and by absorbing them becomes warmed, while the fiercest rays of the sun may pass through a dry atmosphere without heating it above the freezing point. This explains the sudden fall of thermometers on lofty mountains when the sun goes down. With no cloak of vapor to restrain the radiation, the mountain-top cools rapidly. Indeed, so great is the radiation, that unprotected thermometers fall fifteen or twenty degrees below those properly covered, in the same position. The coldness of mountains eminently fits them for condensers of the vapor carried in the wind. The Rocky Mountains thus condense the vapor from the Pacific, and the result is that the dried west wind makes a desert of their eastern slopes. The ice on the top of Mont Blanc is exposed to greater intensity of sun-heat than rests on the plains below; but there is nothing to keep the heat there, and it flies off. Travellers who ascend this summit of ice have to protect their faces from the heat, direct and reflected, which would else blister and burn them, while at the same time they are slipping over ice that shows no signs of melting.

The same remarkable changes in day and night temperature are seen in less elevated but equally *dry* regions. On the Sa-

hara, where "the soil is fire and the winds flame" during the day, at night the cold is painful, and ice is sometimes formed. In Australia, the daily range of the thermometer is more than 45 degrees. In Bengal, advantage is taken of dry nights to obtain ice from water, placed in shallow pans in pits on dry straw to increase the radiation and to cut off all heat from the earth. In this case it is noticed that on cloudy nights ice is never formed, and not always on clear nights; for though clouds are an indication of dampness, clearness does not always prove that the atmosphere is dry.

The warmth of the sea-coast and of islands is accounted for by the protecting vapor which always pervades the air, and retains during the night the heat that the sun has given during the day. On this account the winters in Iceland are not more severe than those in Lombardy, since, in spite of the higher latitude of the former, its vapory cloak lent by the sea counterbalances the radiation of dry Lombardy. It has been shown that, if the vapor of England could be removed for one winter, every tree and plant that could not bear a severe frost would become extinct. May not the cold of Central Asia at the present time, while anciently the elephant found the climate genial, be accounted for by supposing the moisture of the atmosphere to have been removed by the upheaval of mountains which act as condensers on the moist winds blowing north and west?

The heat of our summer does all the work of vegetation. Every particle of heat that is not dissipated into space is converted into some tiny bud, which grows only by converting more heat into its cells and fibres. Where the season of warmth is short, mosses and lichens grow. As we recede from the arctic regions, the summers are longer and hotter, and the vegetable growth becomes more complicated and extensive, until where summer is perpetual plant-life reaches its maximum, as animal life does also. To the plant, whose office is to grow, heat and moisture are requisite; but, for the reasons we have seen above, in a moist atmosphere the heat received will not escape; so that a more sensitive organization, like that of man, cannot endure what in a dry air would be neutralized by the evaporation of perspiration. Men have remained in a dry oven while a steak was cooked at their side; but in

steam of the same temperature they would have been boiled to death. Perhaps in no department of science does the careful providence of the Creator illustrate itself more richly to our distinct cognizance than in this.

In the Lectures under review, the want of actual experiments which presents itself to readers on this side of the water — a want which must continue to be felt until we have more ample scientific endowments than at present — is compensated by illustrations and exceedingly lucid explanations. The fact that the lecturer has discovered or amplified many of the phenomena he treats of, gives to the work a life and interest seldom found in so-called "popular scientific lectures." It thus becomes, not a dry compilation of facts, but an illustrated history of the progress of the branch of science to which Professor Tyndall has devoted many years of careful study.

ART. VII. — 1. *Lectures on the Science of Language, delivered at the Royal Institution of Great Britain, in April, May, and June*, 1861. By MAX MÜLLER, M. A. London. 1861. New York. 1862.

2. *De l' Origine du Langage.* Par ERNEST RENAN, Membre de l'Institut. Paris. 1859.

3. *First Principles.* By HERBERT SPENCER. London. 1862.

IN the beginning of that instructive and very amusing dialogue, the Cratylus, Plato makes the sophist observe "that there is a propriety of appellation naturally subsisting for everything that exists, and that this name is not what certain persons conventionally call it, while they articulate with a portion of their speech; but that there is a certain propriety of names, naturally the same, both among Greeks and among Barbarians." In proof of this, Cratylus denies that his friend Hermogenes is correctly so called; because, being neither wealthy nor eloquent, he manifestly cannot be deemed, in any sense, the "offspring of Hermes." The ensuing discourse, to which these remarks are